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PATENT SPECIFICATION

DRAWINGS ATTACHED

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COMPLETE SPECIFICATION

Improvements in and relating to Electron Multipliers

We, WILLIAM H. JOHNSTON LABORATORIES, INC., a corporation of the State of Maryland, United States of America, of 3617 Woodland Avenue, Baltimore 15, Maryland, United States of America, do hereby declare the invention for which we pray that a Patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This application relates to electron multiplication, and more particularly, to an electron multiplier in which a focusing affect is achieved with a grid type of structure.

Electron multipliers are in general use today for a number of different purposes. For instance, such multipliers are employed to furnish a high intensity source of electrons, are employed to change a photographic image into an electron image, with appropriate multiplication or amplification thereof, and are further employed in conjunction with counting of ions, electrons, and other forms of radiation in, for instance, mass spectroscopy.

Electron multipliers currently available on the market may be divided into three fundamentally different types. The first type employs magnetic focusing, while the second type employs pure electrostatic focusing. The third type available is the type most nearly similar to that of the present invention and employs meshes or grids which are positioned in stacked array between the source of radiation (whether electrons or ions) and the anode from which the amplified stream of electrons is extracted. An alternative form of the grid or mesh type of multiplier is one identified as the "E.M.I.—type" and uses grids which are formed in the design of venetian blind slats.

The grid or mesh type of multiplier is fundamentally simpler and more compact than the commercially-available electrostatic and magnetic multipliers, but the types generally available on the market today are inherently relatively inefficient. In fact, the commercially-available magnetic and focused electrostatic multipliers are generally of considerably higher gain and higher collection efficiencies than the unfocused electrostatic multipliers which use a mesh or grid dynode configuration.

It is an object of this invention to provide an electron multiplier which is relatively compact and simple in comparison ith the commercially-available magnetic and focused electrostatic multipliers, but which also has the high gain and collection efficiencies normally associated with these types of multipliers. It is a further object of this invention to provide a simple and compact construction of electron multipliers, with high gain and high collection efficiency.

These and other objects of the invention are achieved by use of the stacked grid type of construction normally associated in the commercial market with the unfocussed electrostatic multiplier, but to employ such grids, of unique configuration, in conjunction with focusing means such as to enhance the gain and collection efficiency of the multiplier.

The prior art does contain a suggestion of the use of focusing in conjunction with grid or mesh-type multipliers, in British Patent No. 516,621. In this patent a series of stacked grids containing passage-defining depressions of diminishing cross section in the direction of electron travel are disclosed as provided with annular flanges which are successively biased to a higher positive voltage, to provide a degree of focusing. An improvement over the disclosure of this British patent is disclosed in British Patent No. 543,106 in which the grids are disclosed as provided with repressions in hexagonal array, such depressions

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merging with each other adjacent the entrance side of each dynode grid, and terminating at the opposite side in circular holes. Thereby, a number of ridges are provided which are exposed to primary electrons through the holes in preceding dynode grids. Alternatively, the later British patent suggests the use of spherical, rather than polygonal depressions, with a hexagonal array of ridges between each set of six depressions.

It has also been proposed in British Patent No. 531541 to use auxiliary perforate electrodes respectively spaced in front of the cathode electrodes of the array, with the perforations of the auxiliary electrode of each set of auxiliary and cathode electrodes being out of line with the perforations of the cathode, and with the auxiliary and cathode electrodes of each set at the same potential.

The present invention, as distinguished from the subject matter disclosed in the above British patents, employs meshes or grids as dynodes, but with material removed from the dynode plates or sheets in such fashion as to form a single cusp defined by each set of four adjacent holes, with the holes and the depressions extending outwardly therefrom arranged in square, as distinguished from hexagonal, array. Further, the present invention employs focusing plates associated with each one of the dynode plates or grids, with such focusing plates containing cylindrical passages therethrough which are arranged opposite the cusps and therefore expose each cusp of the dynode plate or grid to the primary electrons emanating either from the source or from the previous stage of the electron multiplier. The combination of the dynode and the focusing plate is biased to the same voltage, by being in mechanical contact together, thereby providing for materially-enhanced collection efficiency and greater gain.

As will be indicated more fully hereinafter, the electron multiplier of the present invention employs a number of stages, each one of which consists of a dynode plate or grid of the indicated configuration, and a focusing plate constructed and aligned as described, each stage of multiplication being staggered or displaced in respect of the depressions and holes, as compared to the previous stage, so that primary electrons which strike the cusp of one dynode release secondary electrons which are then directed through the passage of the succeeding focusing plate onto the cusp of the next dynode, with no straight path for primary electrons through the various stages. With the configuration of depressions and holes in the dynodes and focusing plates provided by the present invention, it is possible to manufacture all of these elements in the same identical manner, for a complete electron multiplier of many stages, and to provide for the staggered arrangement by mere 180° rotation of successive stages with respect to the previous stage.

The apparatus of the invention will now be more fully described in conjunction with a preferred embodiment thereof shown in the accompanying drawings.

In the drawings,

Fig. 1 is an exploded perspective view showing the bocusing plate, dynode and insulating rig of one multiplier stage;

Fig. 2 is a plan view of an electron multiplier of the invention, with the guard or focusing plate removed; and

Fig. 3 is a sectional view taken along line 3—3 of Figure 2, but with a focusing plate in position in the first stage of the multiplier.

Referring first to Fig. 1, each multiplying stage of the invention includes as an essential part thereof, a dynode plate 10 which is shown as being of disc-shape with a number of passages 11 indicated as extending therethrough. The passages will be more fully described hereinafter. Each dynode plate is provided with mounting and positioning holes 12 which extend from one opposite face of the dynode plate to the other.

In addition to the dynode plate 10, at least each stage except the first stage of the electron multiplier is provided with a focusing plate 13 which has mounting holes 14 extending therethrough and mating with corresponding holes 12 in the dynode 10. The focusing plate 13 is also provided with passages 15, of cylindrical nature, extending between opposite sides thereof, and the plate, like the dynode plate 10, is of disc-shape, so as to be cylindrical in outside configuration.

The several stages of the electron multiplier of the invention must be electrically isolated from each other, or insulated from each other, and this function may be provided by spacing rings 16 of insulating material. Such rings have mounting holes 17 extending therethrough which register with the corresponding holes 12 and 14 in the dynode and the focusing plate 14, respectively. The rings 16 are hollow, as shown so that the active surfaces of the dynode and the focusing plate through which the holes and passages extend are not covered by the insulating rings.

Referring now to Figs. 2 and 3, the structure of the various elements of the multiplier will be described in more detail. As indicated above, Fig. 2 is a plan view of the electron multiplier shown in cross section in Fig. 3, but with the first stage focusing plate 13 removed. As a matter of fact, it is not at all essential that a focusing plate be provided for the first stage, and in one embodiment of the invention a guard plate consisting merely of a metal disc with a central cylindrical passage therethrough of dimension corresponding to the entire active surface of the dynode 10, was provided, this passage or hole being covered by a conventional wire mesh of about

50 lines per inch. This guard plate then performed the function of establishing a reference for the necessary electrostatic fields of the apparatus, but allowed the electrons or positive ions directed toward the first stage substantially free and unimpeded access to all areas of the first dynode 10.

Alternatively to the structure described immediately above, the electron multiplier could also be provided with a guard plate of characteristics described above positioned in front of the first focusing plate 13, but spaced and insulated therefrom, and this guard plate could form the electrical field termination point for the electrostatic focusing fields of the invention.

Each of the dynode plates 10 of the apparatus of the invention is of any appropriate electron-emissive material such as to have the characteristic of emitting a larger number of secondary electrons than the number of primary electrons or positive ions which strike it. Such a material is a beryllium surface suitably oxidized in well known manner. but this invention is not to be considered limited to any particular kind of secondary electron-emissive material forming the surface of the dynode plate 10. In fact, in one actual construction of the invention, the dynode plate 10 was of a silver-magnesium alloy, with a magnesium oxide coating activated in manner well known to the art.

As indicated above, the dynode plate 10 is provided with a large number of passages 11 extending therethrough between opposite faces of the plate, in the axial direction. These passages 11 extend symmetrically outwardly from central holes 20, in the rear face of the plate, in crater-like fashion, to the opposite or front surface of the plate. The actual configuration of the passages 11 may be more readily understood by a description of a suitable manner or method of making them.

It is desired to leave between each set of four passages 11 through the dynode plate 10, a single cusp 21. This cusp is defined by sloping walls corresponding to intersecting depressions of crater-like form, which depressions terminate in the holes 20. The passages 11 are conveniently made by masking all of the exposed surfaces of the dynode plate 10, with the exception of areas corresponding to the holes at the rear sides of the plates. The spacing of these holes will be described hereinafter, but will be evident from Fig. 2, that the holes are uniformly spaced along the vertical and horizontal directions of that figure. The masking is to protect the plate against etching by a suitable chemical etchant, such as the acids, or acidic materials, ordinarily employed in the printing and printed circuit industries, and may be any of the resist type of materials known depending upon the etchant selected and the metal employed for the dynode plate 10.

When the dynode plate 10, suitably masked or protected by resist material in the manner indicated, is immersed in an etchant of appropriate nature, or an etchant is sprayed thereagainst, the areas of the plate attacked initially are only those exposed by the holes corresponding to the holes 20, in the resist material. Since removal of metal proceeds with equal speed in all directions from the initial hole 20, the spaces left by the etchant will broaden out from the initial holes 20 until the plate is completely etched through. When this result is obtained, the plates are immediately removed from the etchant, and the resistant material may be removed from the plates.

The passages 11 on the front side of the dynode plate will then terminate in surfaces which are curvilinear in nature, with only cusps 21 left between each four of the passages 11. These cusps will be located at a radius (R) from the centre of the hole 20 which is equal to the sum of the radius of the hole 20 and the thickness (t) of the plate 10. If the holes were not of the proper distance apart, but were rather of a larger distance, rather than a cusp 21 the etching process would leave a circular ridge surrounding each passage, with the extent of the ridge between adjacent passages being determined by the distance between passages. However, in the present invention it is essential that only a single cusp be left between each set of four passages, and this result is achieved by choosing the distance (d) between the centers of holes 20 equal to the square root of 2 multiplied by the sum of the radius (r) of holes 20 and the thickness (t) of the plate 10. If this cusp is to be obtained, the radius of hole 20 must be less than the square root of 2 divided by 2, multiplied by the thickness (t), for otherwise no cusp would be left but rather all of the material dividing adjacent holes would be removed. A practical condition for the retention of the cusps 21 is that the radius (r) of the hole 20 be equal approximately to half the thickness (t). The equation forms the relationship is $r < \frac{\sqrt{2}}{2}(t)$.

Another extremely important characteristic of the placement of the passages 11 in the dynode plates 10 is that the rows of the holes in the dynode plates next adjacent perpendicular diameters of the plates be offset from those diameters by substantially one-fourth of the distance between adjacent holes. In other words, referring particularly to Fig. 2, as is indicated by the section line 3—3, the center of the middle horizontal row of holes 20 are spaced downwardly with respect to the diameter passing through the mounting holes 12, by the distance indicated. Also, the centers of the middle vertical row of holes 20 are displaced from the vertical diameter

passing through the upper and lower mounting holes 12 by the same distance. With this arrangement, the dynodes may be all manufactured identically, with the holes and passages all identically located, yet the dynodes of successive stages may be properly positioned by mere 180° rotation with respect to each other, so that the hole 20 in one dynode is opposite the cusp 21 in the next dynode. This relationship is shown in Fig. 3, wherein the second stage dynode plate 10′ has its cusps 21′ opposite the holes 20 in the first dynode plate 10.

The focusing plates 13 may be manufactured in similar manner as the dynode plates 10, but they are merely provided with cylindrical passages 15 which are identically located with respect to the holes 20 in the dynode plates. Then, in each electron multiplication stage, the focusing plate 13 may be positioned such that its passages 15 are opposite the cusps 21 of the associated dynode plate 10, and in the next stage the passages 15′ will then be opposite the holes 20 in the preceding dynode plate. The relative placement of holes and cusps is shown by the dotted outline of these elements in Fig. 2, as well as Fig. 3.

While one very advantageous way of making the passages 11 through the dynode plates and the passages 15 through the focusing plates has been described above, it will be evident that methods of mechanical removal might be devised to perform substantially the same function. Consequently, the invention is not to be considered limited, except where required by the claims, to this particular method of manufacture of these plates, but it will be seen that the surfaces of the dynode plates are specifically most conveniently described by reference to the method of removal employed.

Referring to Fig. 3, it will be seen that the electron multiplier therein shown comprises a series of stages of multiplication, each of which includes a dynode plate 10. These stages are assembled together, with the insulating spacing rings 16 between them and clamped in position, with a solid anode plate 25 at the end of the stack of multiplication stages remote from the entrance of the electrons or ions to which the multiplier is to respond. In other words, the anode plate is adjacent the last stage of the electron multiplier. This anode plate 25 may be provided with mounting holes 26 corresponding to the mounting holes 14, 12 and 17 in the focusing plate, dynode and insulating ring, respectively.

When clamped together, with the aid of mounting rods and clamps, (not shown) the dynode plates 10 and focusing plates 13 will be seen to be in direct physical contact, so that any potential applied to one of them will also be applied to the other. Each stage of multiplication is then spaced apart and insulated from each other.

In order to bias the dynode plates and focusing plates appropriately for acceleration of the secondary electrons emitted from one dynode toward the next stage of multiplication, a suitable source of direct current voltage, such as indicated by the battery 27, may be provided. The voltage from this source may then be subdivided by the usual voltage divider consisting of a series network of resistors, (not shown) to provide discrete voltages which may be supplied to successive stages of the multiplier. Alternatively, and as shown in Fig. 3, the insulating rings 16 may be selected to be of appropriate resistivity to provide voltage drops therethrough so that, with proper selection of the voltage source 27, each stage of electron multiplication is biased to a successively higher positive voltage with respect to the preceding stage.

In operation of the electron multiplier of the invention, the multiplier will either be assembled in its own evacuated envelope, (not shown) or it may be positioned in an evacuated container such as employed for mass spectroscopy investigations. The electrons or ions which are to be amplified may then be directed at the upper surface of the electron multiplier, as shown in Fig. 3, and as indicated by the arrows in that figure. If a guard plate of the type described above is employed rather than the first focusing plate 13, the mesh will cover the entire active area of the first dynode plate 10 and will permit substantially all of the electrons or ions which reach it to pass therethrough and into contact with the surfaces of the passages 11. If the first focusing plate 13 is used, however, only those electrons or ions which pass through the holes 15 will strike the first dynode plate 11.

The dynode plate 10 will be struck by the energizing stream of electrons or ions in the areas immediately surrounding the cusps 21, and will emit secondary electrons of number greater than the number of particles striking it. In other words, for each primary electron or ion striking the region immediately around the cusp 21, a plurality of secondary electrons will be emitted. In the absence of the focusing plates 13, the biases provided by the dynode plates 10 and any guard plate or other device defining a ground plane for the multiplier, would urge such secondary electrons to return to the surfaces from which they were emitted. However, with the focusing plates 13 at the same potentials as the dynode plates 10, the only electric fields operative upon such secondary electrons are those between each dynode plate and the focusing plate of the successive multiplier stage. These fields, which in effect penetrate the holes 20 in the dynode plates 10, tend to accelerate the secondary electrons toward the holes or passages 15 in the focusing plate of the next multiplier stage. As such electrons pass through the passages 15, they strike the surfaces immediately adjacent the cusps 21 of

the next dynode plate and cause such surfaces to emit secondary electrons, in the same manner as did the preceding dynode plate. In this manner, multiplication occurs and the secondary electrons are finally directed to the anode 25 where they are collected for subsequent electronic tube or transistor amplification, or for indication.

It will be understood that the representation of the electron multiplier of the invention furnished by the drawings of this application does not necessarily correspond in size to the actual practical commercial embodiment of the multiplier. In fact, such sizes have been distorted for ease of representation, but it will be evident that the number of passages 11 in the dynodes and the corresponding number of passages 15 in the focusing plates would be much larger than shown.

An illustrative embodiment of an electron multiplier of the invention employs dynode plates which are 0.02 inches thick, with focusing plates which are substantially thinner, and in fact are about 0.004 inches thick. The anode plate, as well as the guard plate, if one is employed, are 0.02 inches thick, like the dynode plates. The dynode plates and focusing plates, as well as any guard plate employed, are provided with an active central area of 1.5 inches diameter. Within this central area are located the passages 15 in the fusing plates and the passages 11 in the dynode plates. There may be 36 holes along the central horizontal line, and 36 holes along the vertical central line, such lines being displaced from the corresponding diameters of the dynode plates by 0.0106 inches. The center of each hole is then displaced from its neighbor in a horizontal and a vertical direction by equal spaces of 0.0424 inches, and each hole is of 0.020 inches diameter.

The number of stages to be assembled together is not at all critical with the invention, and as indicated in Fig. 3, a large number of stages can be assembled and joined together. However, the cusps 21 would normally be quite sharp if made by the etching method recommended, and, to avoid noise caused by field emission from sharp edges, the cusps should be rounded off to about 0.002 minimum radius after etching.

If the standard type of voltage divider is to be employed with the electron multiplier of the invention, the dynode plates may be appropriately provided each with one or more ears extending outwardly from its outer surface, to which electrical connection may be made to provide the stages with the necessary successively higher accelerating voltages. Alternatively the focusing plates could be provided with such ears and connections made thereto.

It will be evident that it is not essential to the present invention that the dynodes and focusing plates be cylindrical in configuration. In fact other configurations are completely feasible. However, it is essential to the present invention that the passages in the dynode plates, and the corresponding passages in the focusing plates, be of square array, with each set of four of the passages in the dynode plates defining a single cusp between them, for the purposes indicated above.

WHAT WE CLAIM IS:—

1. A plural stage electron multiplier for supplying an amplified output corresponding to an input from a stream of electrons or ions, each stage comprising a dynode plate of electron-emissive material having the property of emitting a number of secondary electrons higher than the number of primary electrons or ions which strike it and, in at least each stage but the first stage in the direction of the stream of electrons or ions, a focusing metal plate, with the dynode plates and focusing plates having passages extending therethrough, and with the stages spaced apart along the direction of the passages through the focusing plates, with each stage insulated from the others and with successive stages biased to successively higher positive voltages with respect to the first stage, and further including means for collecting electrons from the last stage, characterized by the fact that the passages extending through each dynode plate are arranged in square array with the surfaces defining each passage sloping outwardly in crater-like fashion from a central hole of radius r in one of the faces of the dynode plate to the opposite face thereof in such fashion that the surfaces of each set of four adjacent ones of said passages define a cusp at radius R from the center of each one of said four holes, where R is substantially equal to r+t, t being the thickness of each dynode plate between its said opposite faces, the said focusing plates being of thickness much smaller than that of the dynode plates and having cylindrical passages substantially of radius r extending therethrough, with the passages of the focusing plate being of the same number and geometrical arrangement as the cusps in the dynode plate of the same stage, and with the focusing plate of each stage having one of its opposite faces in metallic contact with the face of the dynode plate of that stage which bears the said cusps, and with the passages in the focusing plate of each stage opposite the said cusps in that stage, so that primary electrons passing through the passages in the focusing plate will strike the surfaces of the next dynode plate adjacent the said cusps to cause emission of secondary electrons therefrom, each focusing plate of every stage except the first being next adjacent the dynode plate of the previous stage, with the passages through the focusing plate being opposite the said holes in the dynode plate.

2. The apparatus of claim 1 in which each

of said cusps is rounded off to inhibit field emission of electrons.

3. The apparatus of claim 2 in which each of said dynode and focusing plates is cylindrical in shape with the said opposite faces thereof being spaced apart axially thereof and with the centers of the holes in the dynode plates and the passages in the focusing plates which are next adjacent the perpendicular diameters of the plates being offset from those diameters by substantially one-fourth the distance between the centers of adjacent holes.

4. The apparatus of claim 3 in which the distance d between the centres of each pair of adjacent holes in each dynode plate is substantially equal to the square root of 2 multiplied by the sum of the radius r of that hole and the thickness t of the dynode plate.

5. The apparatus of claim 4 in which the surfaces defining the passages through the dynode plates are shaped correspondingly to the surfaces which would result if each dynode plate had all of its surfaces masked against an etchant for the plates except for the areas of said holes in the dynode plates, and the dynode plate were immersed in such etchant for a time sufficient for etching to proceed through the plate from the face bearing said holes to the opposite face.

6. The apparatus of claim 5 in which said electron-collecting means is a cylindrical anode plate aligned with but insulated from the dynode of the last stage of the multiplier, to receive and collect secondary electrons emitted therefrom.

7. The apparatus of claim 6 in which said biasing means includes ring shaped insulators in contact with to space apart the rims of the metal plates of adjacent stages and the anode plate, said insulators being of predetermined resistivity, and a direct current voltage source connected between the first stage and the anode plate, said source supplying a voltage of magnitude in comparison with the resistivity of said insulators such as to appropriately bias each stage in accordance with the voltage drop across each insulator.

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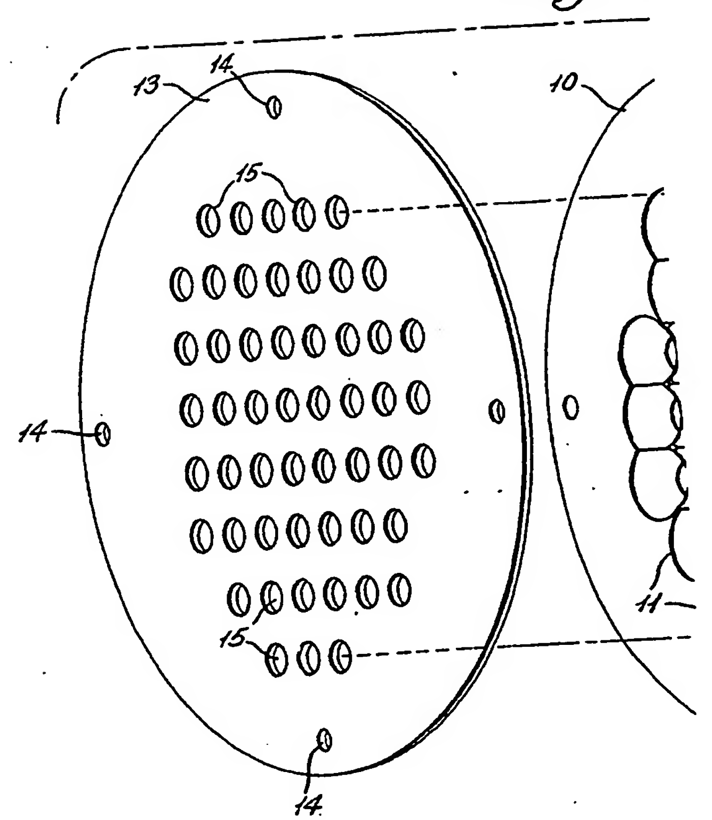
Fig. 1



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Sheet 1

Fig. 1.

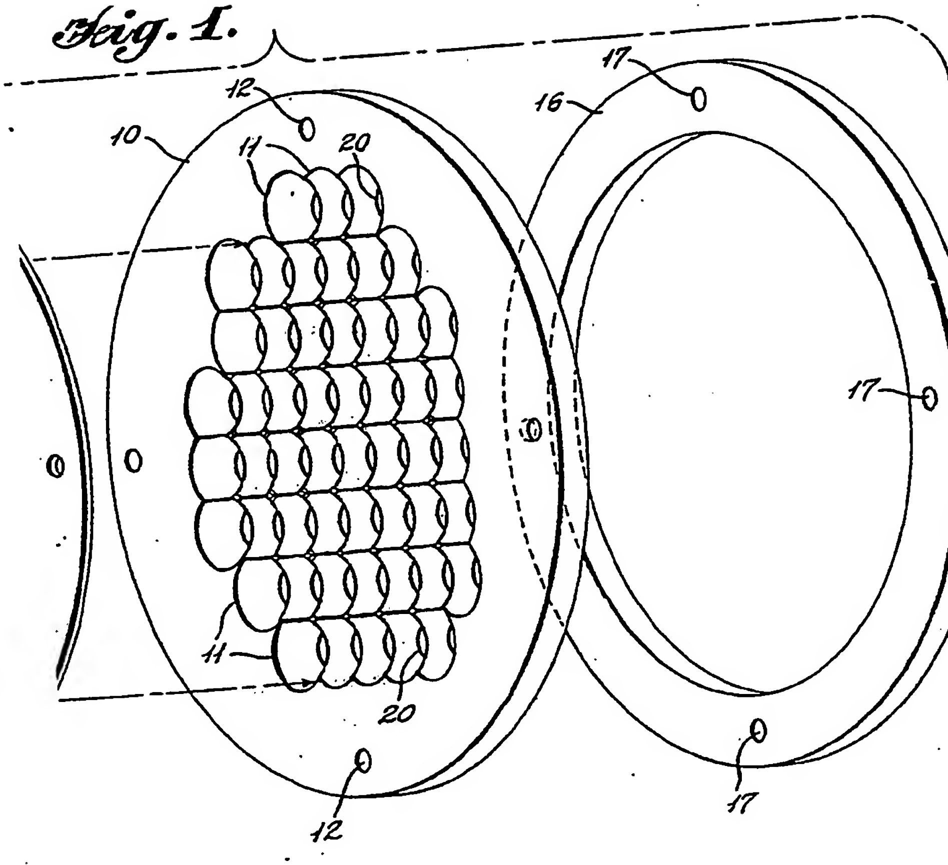

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Fig. 1.

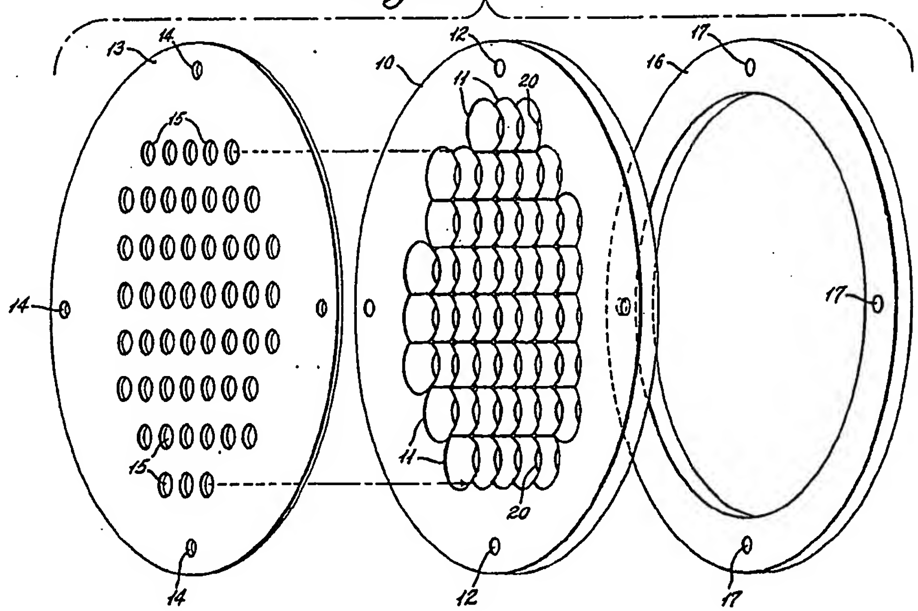
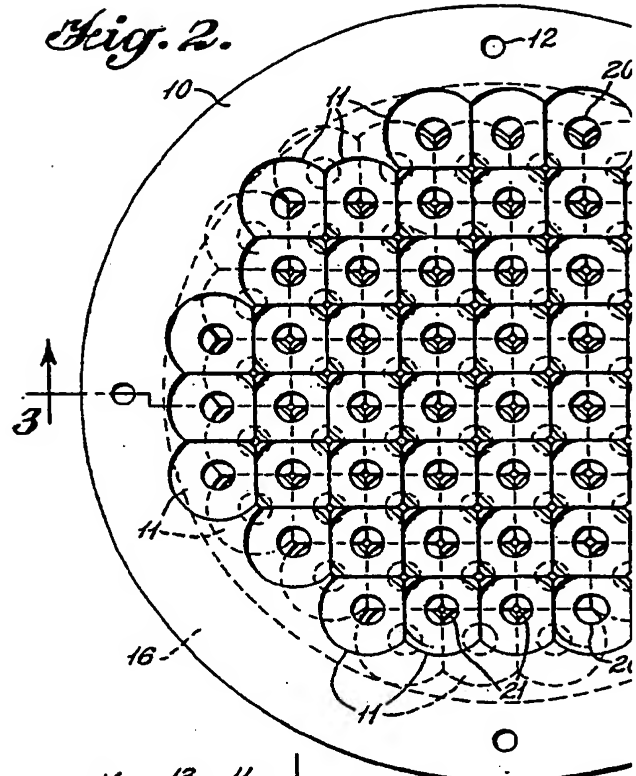


Fig. 2.



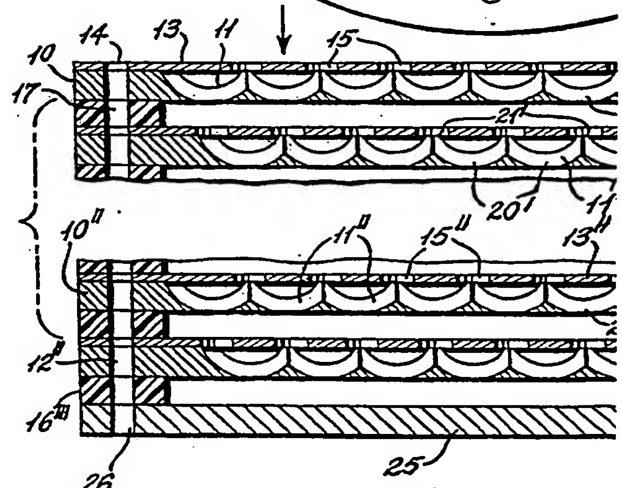


Fig. 3

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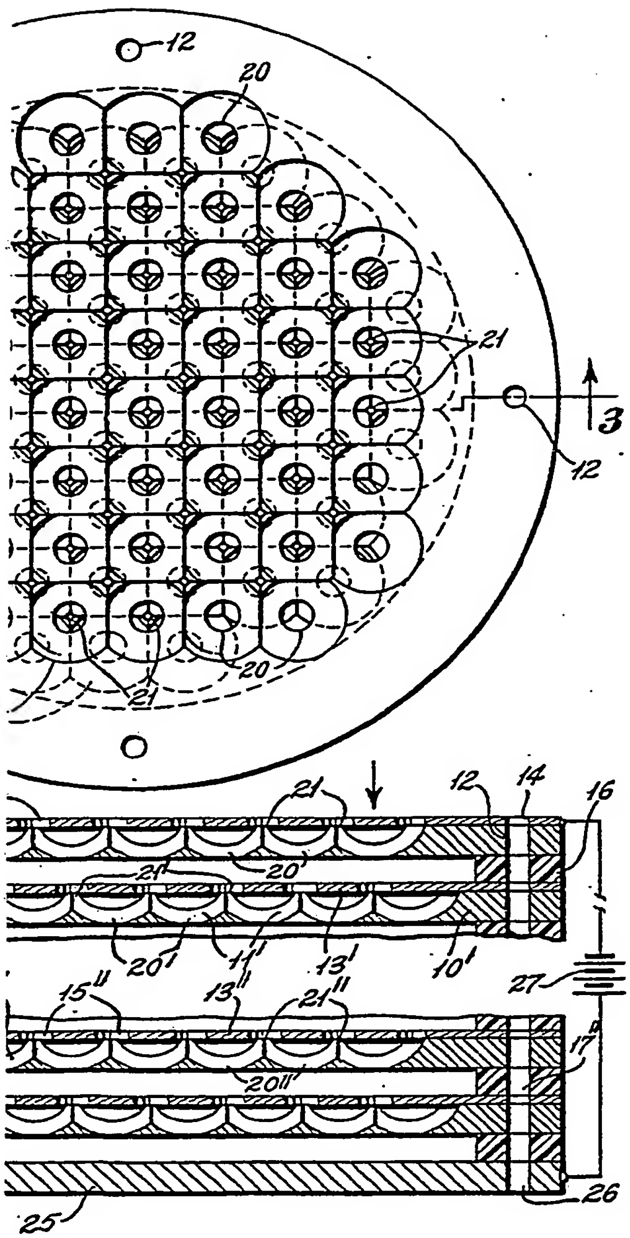

Fig-3

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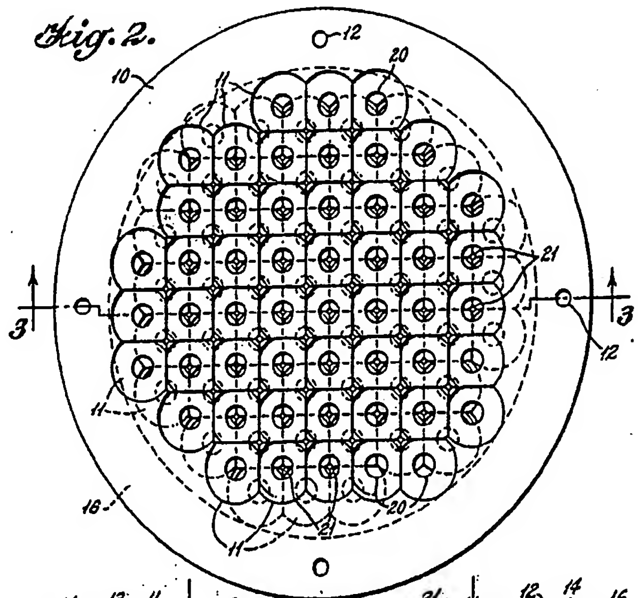
Sheet 2

Fig. 2.



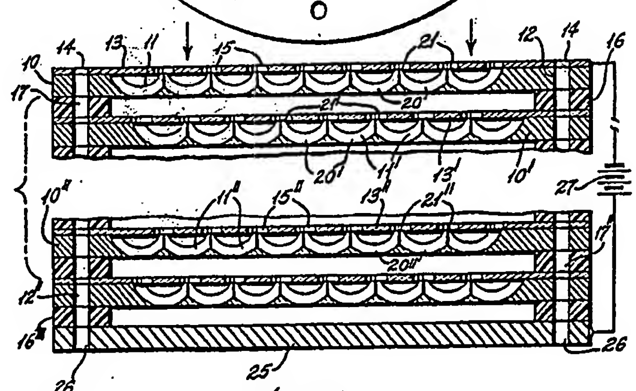


Fig. 3